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What are people really eating? The relation between energy intake derived from estimated diet records and intake determined to maintain body weight[1,2]

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ABSTRACT Two hundred sixty-six free-living human volunteers, 21–64 y old, were trained by dietitians to record daily their food intake for at least 7 d. Subsequently, they were fed diets of conventional foods adjusted in amounts to maintain their body weight for ≥ 45 d. Comparing their estimated energy intake with the intake determined to maintain weight yielded mean differences of 2365 and 1792 kJ (565 and 428 kcal) in men and women, respectively, representing an underreporting of 18%. Twenty-two individuals (8%) overestimated and 29 (11%) were accurate to within 419 kJ (100 kcal) of their maintenance requirement. The remaining 215 individuals (81%) reported their habitual intake at 2930 ± 1586 kJ (700 ± 379 kcal) below that subsequently determined as their maintenance requirement. These findings suggest caution in the interpretation of food-consumption data. *Am J Clin Nutr* 1991;54:291–5.

KEY WORDS Diet records, energy needs, food intake energy requirements, dietary intake, nutritional assessment

Introduction

Accurate measurement of food intake is the most basic prerequisite of a science that studies the metabolism of nutrients in the organism and correlates intake with various health effects. Nutrient intake in human subjects can be well-controlled in metabolic-ward studies and only somewhat less in well-designed feeding trials of free-living subjects. Controlled studies are relatively few compared with the many attempts to determine food intake by relying on recollections or records of individuals rather than on direct, independent observations. The results of dietary surveys, whether limited in size or national in scope, constitute a database that strongly influences the accuracy of many important conclusions relating to nutritional status or to risk for certain diseases in populations or their subgroups. Much effort has been spent by epidemiologists and dietitians to improve methods to estimate food intake of individuals, but usually the results still depend on the word or written note of the individual participant and cannot be validated independently.

This publication presents a comparison between subjective diet records and objective determinations of the energy intake that maintains weight over reasonable periods of time in human subjects. Long-term studies performed in free-living subjects at the Beltsville Human Nutrition Research Center over the past 14 y have led to the suspicion of a systematic underreporting of food intake by volunteers and to the publication of a limited amount of data suggesting a nutritionally significant bias (1–3). These publications created little discussion or concern (4), possibly because of the small number of data presented. We now present the complete set of energy-intake data, covering all of our qualifying human studies at this center, and compare the results with those of our earlier studies and with more recent observations by others (5–9) suggesting systematic underreporting of energy intake.

Subjects and methods

The data presented here are based on 14 y of human-intervention studies at this center that met the following criteria: thorough training of the participants by our dietitians, complete food-intake records for ≥ 7 d (range 7–35 d), and consumption of a defined experimental diet for ≥ 45 d with weight maintenance to within ±0.9 kg during that period. Twelve human studies met these criteria with an average duration of 104 d (range 45–227 d). Two hundred sixty-six human volunteers (203 males and 63 females), aged 21–64 y and representing 29 585 volunteer days, participated in these studies. The subjects were recruited through local advertisements in the area surrounding Beltsville, MD. The final participants were selected after a thorough medical evaluation diagnosed them to be free of diseases or chronic conditions and not to require any medication. Interviews and questionnaires eliminated those with extreme dietary habits or nutritional-supplement use.

Although the 12 intervention studies evaluated here had very different protocols, they all followed one basic design and began with training sessions. Our registered dietitians interacted with the participants in groups of ≤ 10. The sessions lasted 1 h and included explanation of the diet questionnaire (10); demonstration and practice in the use of scales, measuring spoons, and

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cups; and instructions on estimating portion size without measuring devices (for meals consumed away from home). The classes concluded with a question and answer period. The participants took the measuring devices home to determine the amount of food eaten as accurately as possible by actually measuring or weighing. The resulting diet records were scrutinized daily (except on weekends) by our dietitians in the presence of the individuals so that any questions as to quantity, incomplete entries, or vague descriptions could be resolved at that time. The subjects recorded their food and drink intake daily for at least 7 d. They were admonished to continue with their habitual lifestyle, especially physical activity, and not to change their dietary intake.

The diet records were carefully evaluated for energy and nutrient contents, and the participants were subsequently fed diets consisting of whole foods and approximating the composition of the American-type diet. The energy requirement of each individual was estimated from the tables of the recommended dietary allowances (RDAs) (11, 12), taking into account body weight, height, and activity. During the period covered by our studies, we used two editions of *Recommended Dietary Allowances* for the estimation of energy needs, those of 1974 and 1980. They are very similar in their recommendations for energy intake.

The participants were weighed five times per week in minimal clothing, before breakfast. 900-g weight change persisting for ≥ 2 d was followed by an adjustment in the amount of the diet fed in steps of 837 kJ (200 kcal) in women and 1674 kJ (400 kcal) in men until weight stabilized. This was achieved in most cases during the first week; occasionally the adjustment required 2 wk.

The experimental diets consisted of whole foods but varied in their composition, depending on the experimental design. Examples are low-fat (25% of energy) vs high-fat diets (40% of energy), low- vs high-sugar diets, changes in the amounts of fiber, comparison of different starches, etc. A typical diet pattern was published (13). All diets met or exceeded the RDAs from their natural ingredients except for calcium, which had to be supplemented for those with low energy intakes. Because all the studies dealt with physiological variables that can be influenced by changes in body weight, it was essential to maintain the body weight of all participants throughout the intervention.

The participants continued all aspects of their habitual activities except food consumption. Those accepted into studies agreed to consume only food and drink provided by the Nutrition Research Center except for noncaloric soft drinks and coffee and tea. For the latter two, sweetener and milk were supplied as part of the daily diet. On weekdays the participants consumed breakfast and dinner in the dining room of the center but were given a prepared lunch and snacks, which they ate at their place of work. The weekend meals, also including snacks, were prepared for home consumption and distributed frozen in insulated containers during Friday's dinner. Consumption of all food served during breakfast and dinner was supervised by our dietitians; consumption of lunches and weekend meals was verified by interviews. Incomplete consumption was extremely rare; the deficit was measured and recorded. Occasional overconsumption, on the other hand, could not be ruled out with certainty, even though the participants were highly motivated.

Individual food records were coded from a descriptive list of food items in a database from various sources, which was updated with more-current data as they became available over the years covered by the controlled dietary studies. However, the principal source from the earliest years to the present has been the Nutrient Data Bank from the US Department of Agriculture (USDA), Human Nutrition Information Service. The earliest version of the database for these studies was compiled from the tape for individual intake measurements in the USDA's 1977–1978 Nationwide Food Consumption Survey (14) and a tape of *Agriculture Handbook no 456* (15). Updated information, principally from revised sections of *Handbook no 8,* was added as it became available (16). Additional data for specific food items were obtained by analysis, from the food industry, and from other databases and were added as needed. Although our database became more complete over the years, identical data for the evaluation of diet records and the design of the diets to be fed were used for each of the 12 studies reported here.

Paired t tests were used to determine significance of differences between reported and experimentally determined energy intakes in each group. Gender differences were assessed by Student's t test. Pearson correlation coefficients were used to determine the relationships of age and weight to the differences between reported and determined intakes (17). The probability level of $P < 0.05$ was set for statistical significance.

The protocols for these studies, including informed consent statements, were approved by the Agricultural Research Service's Human Studies Review Committee after approval by appropriate institutional review boards.

Results

Of the 266 participants, 215 (81% of the total; 75 females, 82 males) reported their habitual energy intake at 2930 ± 1586 kJ (700 ± 379 kcal, $\bar{x} \pm$ SD) below the intake subsequently determined to maintain body weight. Twenty-two subjects (8%; 11 females, 7 males) reported an intake higher by 1708 ± 1076 kJ (408 ± 257 kcal) than their maintenance requirement, and only 29 (11%; 14 females, 10 males) reported intake to within ±419 kJ (100 kcal) of their energy needs. Their mean estimate was accurate to within 7.4 ± 251 kJ (1.76 ± 60 kcal).

Evaluation of all subjects (**Table 1**) showed a mean difference between recorded and determined intake of 2365 kJ (565 kcal) in men and of 1792 kJ (428 kcal) in women. This represented an underreporting of ~18% in both groups ($P < 0.0001$). Thus, the sex of the participants did not influence the degree of underreporting. Also, there was no significant relation between age or weight of the participants and the relative error (error/1000 kcal) of their reporting. On the other hand, the body mass index (BMI, in kg/m^2) was inversely correlated with the reporting error ($r = -0.24$, $P = 0.0001$). This correlation suggests that the linear relationship of underreporting to BMI accounts for only 6% of the variance; it loses further significance when the relative error is used ($r = -0.14$, $P = 0.03$).

A comparison of the estimated with the actual energy consumption resulted in a significant linear correlation presented in **Figure 1** and **Table 2.**

Discussion

The results of this study, if they can be generalized, will have a substantial impact on the interpretation of our national survey data and, indirectly, on the assessment of nutritional status of the population. Therefore, it is appropriate to examine whether any bias in the design of our human studies could have accounted for the substantial bias in the reporting of intake data.

1) Databases. The same Beltsville database used to calculate the reported energy intake of the subjects also served to design the diets that the subjects were subsequently fed.

2) Instruction of the volunteers. It was clearly in the interest of all people responsible for the studies, including the dietitians, to arrive at an exact record of the energy requirement of the study participants to facilitate weight maintenance during the controlled-diet phase of the study. Thus, the dietitian instructors were motivated to train the volunteers to report with the greatest accuracy possible. (The instructions were provided by two dietitians, PDS and EL; EL had attended a training course for taking diet records at the Nutrient Coding Center, Minneapolis.) The volunteers were aware that their diet records would have some function in the study but neither they nor the dietitians nor, initially, the authors of the present publication anticipated the results reported here.

3) Adequacy of 7-d record. As our previous 1-y Beltsville study showed, the energy consumption calculated from 7-d records of trained subjects (9 540 MJ, or 2279 kcal) is not significantly different from that derived from records kept daily for 1 y (9 439 MJ, or 2255 kcal) (10).

4) Bias in the selection of the study participants. The participants, during the nearly 18 y of our studies, reported energy intakes very similar to those reported in recent national surveys. The reported intake of our 203 male participants of 10 557 MJ (2522 kcal) compares with a reported intake of 10 716 MJ (2560 kcal) in males of the 1985 survey (18). The reported intake of our 63 female participants of 7 920 MJ (1892 kcal) is even higher than the mean of 6 396 MJ (1528 kcal) reported for all females in the 1985 survey (19), and all values are within the range reported in the various national surveys (20). Both values are also similar to the energy intake during the 1-y Beltsville study (10). This does not suggest any particular abnormalities in the composition of our volunteer population.

5) Potential faults in the determination of maintenance energy requirement. The energy contents of the diets were calculated by our dietitians and foods were prepared and weighed to the nearest gram by our trained cooks and food-service workers. Subsequent analyses of diet composites confirmed the calculated values (13). Breakfast and dinner during weekdays was supervised by our dietetic staff to ascertain total consumption of the food served. Although no supervision was present during weekday lunches and weekend meals, there was no indication of wasting the prepared meals. If there was any doubt about the reliability of the participants, it would have been about the occasional consumption of an extra snack or drink resulting in greater-than-scheduled energy intake. These considerations offer no proof of strict adherence during the nonsupervised meals but they suggest that throughout the study the controls against wasting food greatly outweighed those against the consumption of unscheduled, additional food or drink.

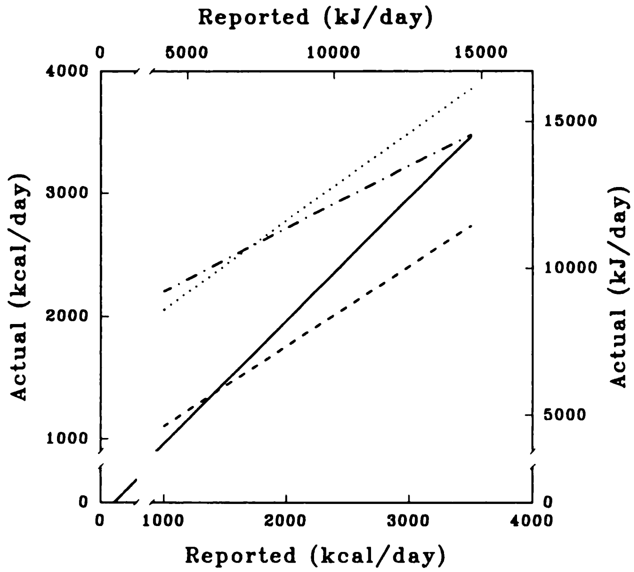

FIG 1. Calculated regressions between reported and experimentally determined energy intake to maintain body weight. All regressions $P < 0.01$. ——— Records within 419 kJ (100 kcal) of maintenance energy (n = 29); -------- records overestimate maintenance energy by > 419 kJ (n = 22); · · · · · records underestimate maintenance energy by >419 kJ (n = 215); and -·-·-· all subjects (n = 266).

The data presented here confirm and extend our previous observations and those of others from smaller studies (1–9). Especially, they agree with a recent study from the United Kingdom (5) in which 1-wk diet records of 31 trained subjects were found to underestimate the energy expenditures by ~20% as compared with 18% in our study. The importance of this close agreement is reinforced by the fact that different methods were used to

TABLE 1
Recorded vs experimentally determined weight-maintenance energy intake*

Subjects	Reported diet records	Determined intake	Difference: Actual	Difference: Percentage
	MJ (kcal)		*MJ (kcal)*	%
Men (n = 203)	10.557 ± 2.332 (2522) [10.252]	12.922 ± 1.704 (3087)† [12.767]	−2.365 ± 2.080 (−565) [2.528]	−18.1 ± 15.7
Women (n = 63)	7.920 ± 1.976 (1892) [7.706]	9.711 ± 1.340 (2320)† [9.628]	−1.792 ± 2.060 (−428) [1.582]	−17.6 ± 19.3

* $\bar{x}$ ± SD. Median in brackets.
† Significantly different from reported value (paired t test), P = 0.0001.

TABLE 2
Correlations of recorded vs experimentally determined weight-maintenance energy intake*

Group†	Intake: Recorded (x)	Intake: Fed (y)	Regression	r	P
	MJ (kcal)				
A (n = 29)	11.486 ± 2.126 (2744)	11.945 ± 2.173 (2746)	$y = 1x - 38$	0.99	<0.01
B (n = 22)	13.743 ± 2.420 (3283)	12.035 ± 2.097 (2875)	$y = 0.78x + 325$	0.9	<0.01
C (n = 215)	9.335 ± 2.114 (2230)	12.265 ± 2.110 (2930)	$y = 0.72x + 1333$	0.72	<0.01
D (n = 266)	9.933 ± 2.512 (2373)	12.160 ± 2.118 (2905)	$y = 0.51x + 1692$	0.61	<0.01

* $\bar{x}$ ± SD.

† A: records are within ±419 kJ (100 kcal) of maintenance energy; B: records overestimate maintenance by > 419 kJ (100 kcal); C: records underestimate maintenance by > 419 kJ (100 kcal); and D: all subjects.

estimate energy requirement, ie, measured intake for long-term weight maintenance vs measurement of energy expenditure by the doubly labeled water method. Another agreement between the two studies, despite the different background of the two populations, is the similarity in the proportion of the subjects underestimating their energy requirement or maintenance intake (81% in Beltsville vs 84% in the UK study).

Our data also tend to confirm observations that subjects who report the highest food intake estimate their maintenance energy needs more closely than do those who report lower intakes (5, 6). A clear difference was also evident in our study (eg, Table 2, groups A and B vs group C) but there were also those individuals who overestimated their energy needs very markedly and reported by far the highest intakes (Table 2). This fact argues strongly against applying a correction factor (eg, of 18% in our study or 20% in the UK report) to calculate true energy needs from diet records of individuals. That practice would be of doubtful validity even in the evaluation of larger groups, because the factors that influence degree and direction of misreporting are unknown and may be different for different populations.

A correlation between recorded and experimentally fed number of calories in each individual in the Beltsville study makes possible some additional interpretations and raises some interesting questions. As expected, the correlation coefficient between reported and fed calories for those estimating their maintenance intake accurately to within 419 kJ (100 kcal, n = 29) is near unity and the intersect of the resulting curve with the y-axis is not different from zero (Fig 1). The coefficient for the remaining groups, even for those underreporting, is significantly below unity, suggesting a maintenance need of < 4.19 kJ for each kilojoule (1 kcal for each kilocalorie) reported in the records, ie, over- rather than underreporting. The intercept of the resulting curves with the ordinate (actual intake), however, changes this interpretation. When all subjects are looked at together (Fig 1), they underreport intakes of < 14 442 MJ (3450 kcal), are accurate at that intake, and overreport at higher amounts of consumption. These considerations suggest that underreporting of energy intake is more likely to occur at lower than at higher intakes. This pattern, however, becomes more complicated when the influence of the BMI is considered. The small biological importance of the association between BMI of all participants and reporting error increases marginally when the latter is examined separately for the group of underreporters. The equation describing that association ($y = 23.1 - 0.0028x$, $P = 0.0001$, where y = BMI and x = kcal reporting error) signifies an increasing degree of underreporting with increasing BMI but accounts for only 7.8% of the variance. Conversely, the equation describing the data of the overreporters ($y = 23 + 0.0032x$), which does not reach statistical significance, suggests an increasing degree of overreporting with increasing BMI. Both equations suggest zero error at BMI = 23, which is close to the mean BMI (23.9) of the group estimating their energy requirement to within 419 kJ (100 kcal). These considerations suggesting only a weak influence of the BMI offer no help for the understanding of the nature and direction (9) of the reporting error.

Our data give no indication as to which components of the diet were underreported in our study. It is tempting to speculate that alcoholic beverages and/or between meal snacks could account for the differences but there is no proof for that assumption. Moreover, it appears very unlikely that fully 81% of our study population knowingly and systematically would have cheated. This leaves us with the tentative conclusion that the underreporting was most probably subconscious, motivated by the belief, widespread in our society, that maintaining a low body weight contributes to good health and that eating less will have beneficial effects. (If this assumption is correct, individuals in societies that find a greater body weight and higher food intake desirable should tend to overreport intake). Whichever the cause, a thorough study of the psychological basis for reporting food intake appears to be needed.

From our results and those of previous studies, we can draw the conclusion that although some well-motivated and trained volunteers of both sexes can reliably record their habitual food consumption under certain conditions (21, this paper), the great majority in the United States underestimate their intake, resulting in a mean discrepancy between actual and reported intake of ~18%.

Discussing the results of the present study in the context of the earlier Beltsville 1-y dietary intake study (10) leads to our hypothesis of the uncertainty principle of food-intake measurements: the degree of deviation of reported from real intake is proportional to the degree of attention focused on the intake. If imposing on individuals only the task of recording their food intake led to an underestimate of 18%, the imposition of yet another task, collection of duplicate food portions, reduced the intake estimates by an additional 13% (10). Actual analysis of duplicates collected in that study by bomb calorimetry provided evidence that the available energy content of the duplicates was

~10% less than the reported available energy intake (10), suggesting undercollecting or a true reduction of food intake in addition to underreporting. It is therefore not surprising that there were apparent negative balances for calcium, phosphorus, magnesium, zinc, copper, and manganese in the four balance periods of the 1-y Beltsville Study.

All these considerations point to the need for great caution in the interpretation of intake data, whether self-reported or obtained by independent observers of whose presence the individuals are aware. If the correction factor of +18% suggested by our study could be applied to national survey data, then our nutritional situation with regard to even the problem nutrients would not be as critical as the original data suggest nor would the gap between the per capita availability of nutrients and their consumption be quite as large as formerly suggested.

Our data and our hypothesis of the uncertainty principle of food-intake measurements call for confirmation or rejection on the basis of larger, independent studies for which reliable methods are now available. It is not known whether underreporting is nutrient neutral or whether it distorts the actual nutrient balance. The psychological aspects of underreporting are not well known and strategies to avoid or correct for underreporting of food intake have not yet proved effective. To arrive at such strategies and to test and implement them in future surveys appear to be a high priority of nutrition research.

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